

Bob Pease
Lab notes 2005

RAP 2005

What's All This

- Common

Mode

Rejection

Stuff?

(Anyhow....)

/RAP

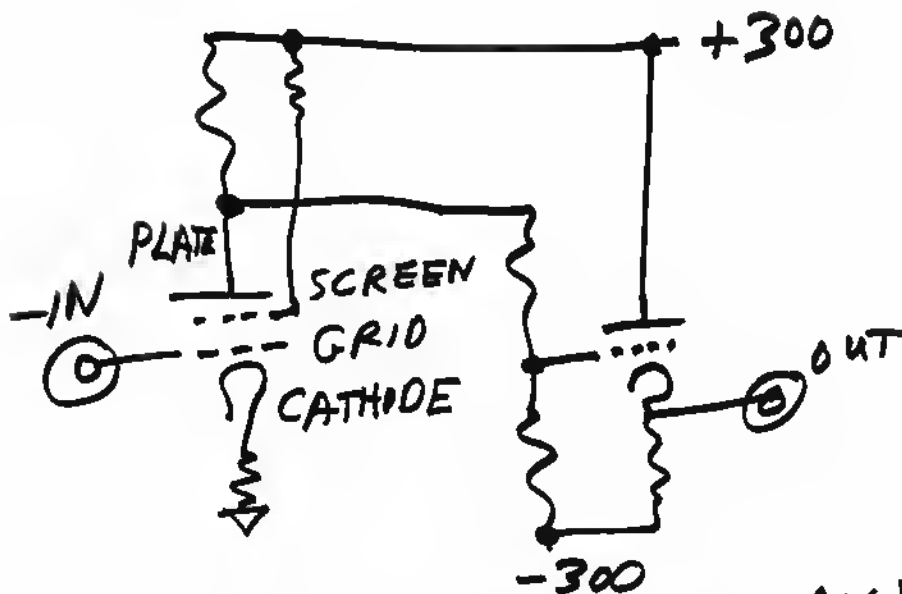
PART I: HISTORY....
R.A. PEASE...

PART II -
— How to test Op amps
for CMRR

PART III
DESIGN FOR RAIL-TO-RAIL
CM Range

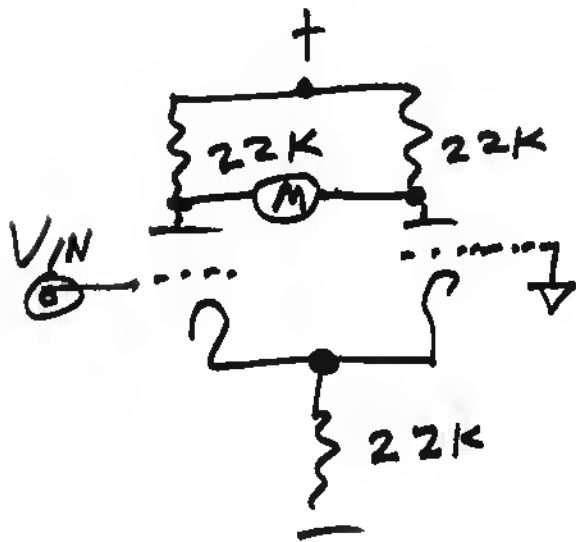
Part IV CIRCUIT DESIGN
FOR GOOD CMRR

ONCE UPON A TIME...

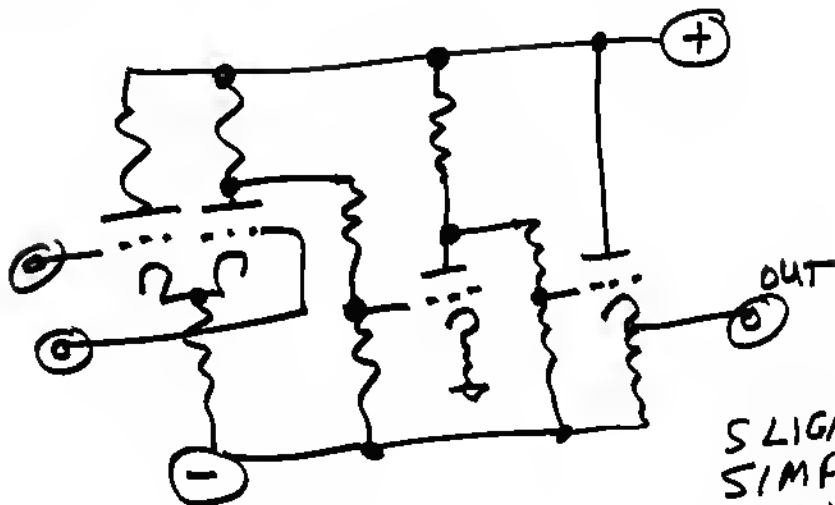


- OP AMPS DIDN'T HAVE
ANY COMMON-MODE RANGE...

YES, DIFFERENTIAL AMPLIFIERS
WERE INVENTED IN THE
1920'S...



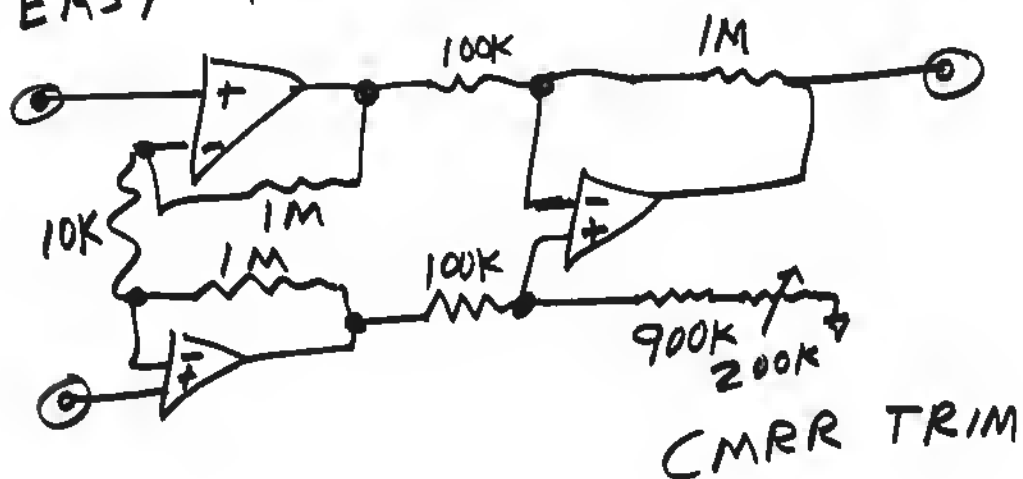
AND THE K2-W CAME
ALONG ~ 1952



SLIGHTLY
SIMPLIFIED ...
... $\frac{1}{2}$ = 1/2 12AX7

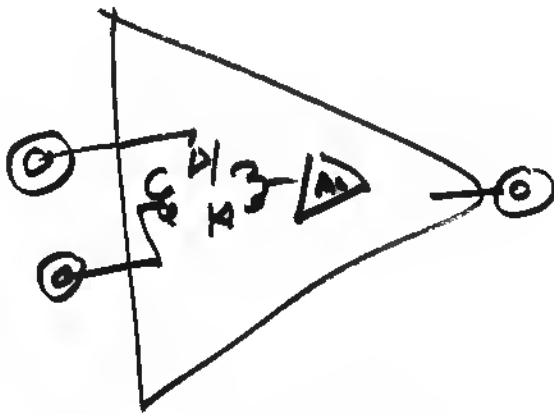
CMRR \approx 300 for $\pm 50V$

STILL - Differential Amplifier
CIRCUITS WERE NOT
EASY TO DESIGN WITH TUBES...



[VOS TRIM NOT SHOWN]

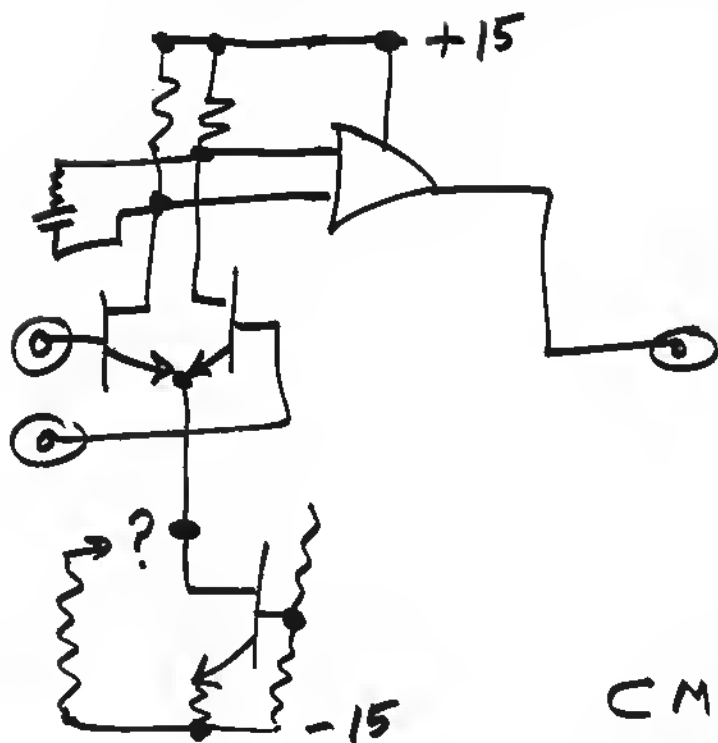
THE PHILBRICK P2 USED
8 GERMANIUM TRANSISTORS TO
PROVIDE A ± 200 VOLT
CM RANGE



THE CMRR WAS $\sim \infty$
- IN 1961....

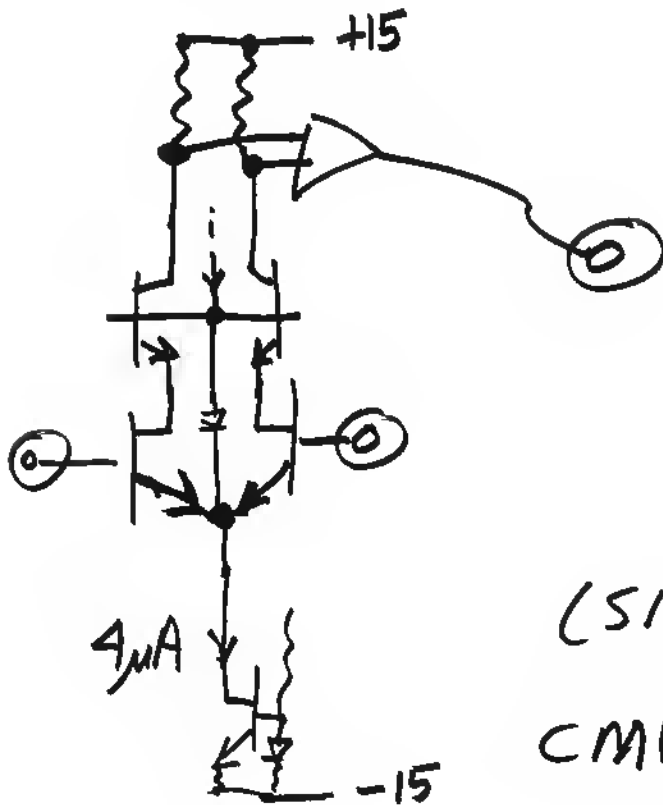
BOB

SILICON TRANSISTORS
MADE GOOD OP-AMPS
POSSIBLE



$CMRR > 10,000$ WITH
GOOD MATCHED NPN'S....

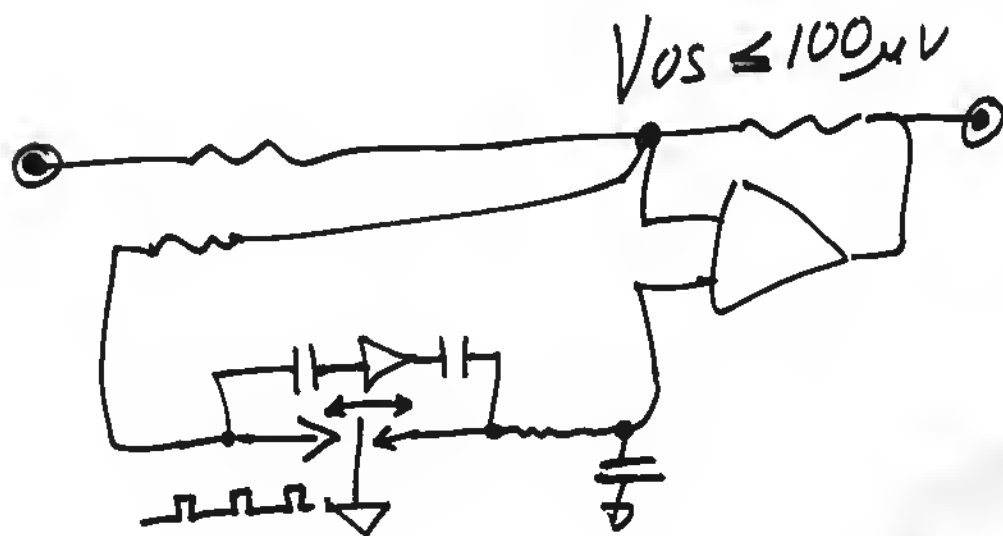
BOB WIDLAR'S LM108
MADE HIGH CMRR
FEASIBLE



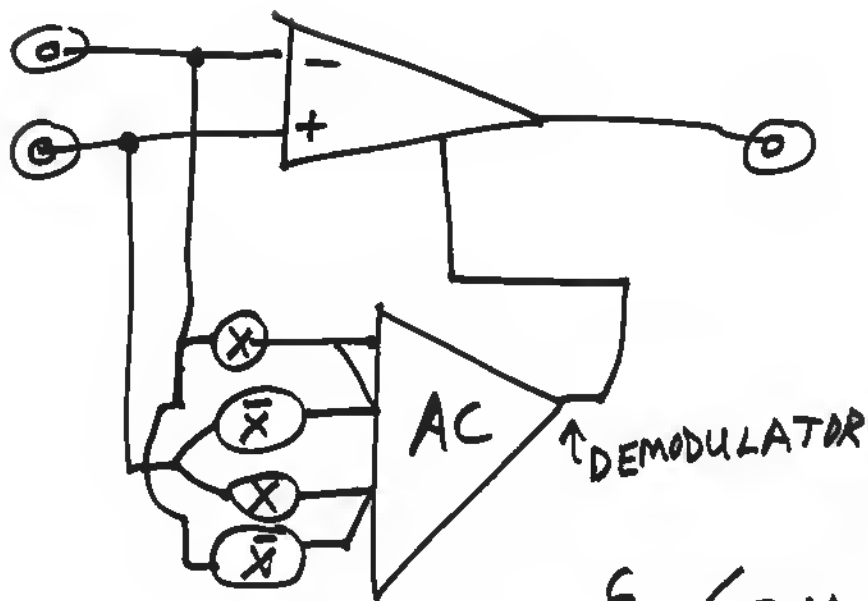
(SIMPLIFIED CIRCUIT)

$CMRR = 100,000$
TYP.

CHOPPER-STABILIZED
AMPLIFIERS USED TO GIVE
LOW OFFSET - BUT ONLY AT
GROUND



CMOS CHOPPERS MAKE
GOOD CMRR FEASIBLE UP TO
+ 2.7V



$CMRR > 10^6$ (3M typical)

WHAT'S ALL THIS

COMMON

MODE

REJECTION
STUFF?

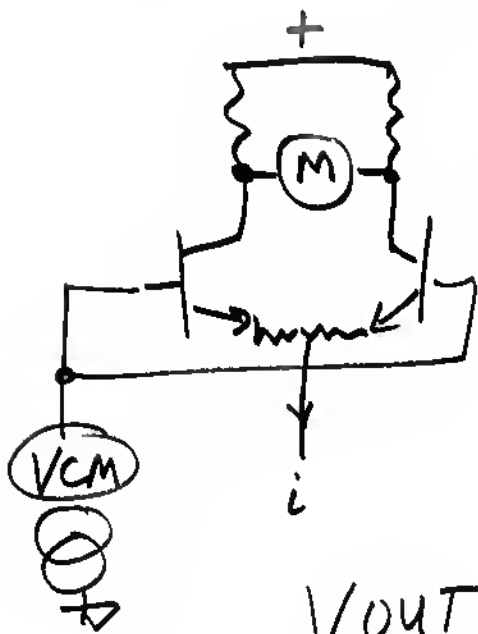
(ANYHOW.....?)

PART II:

HOW TO MEASURE

OP-AMP CMRR....

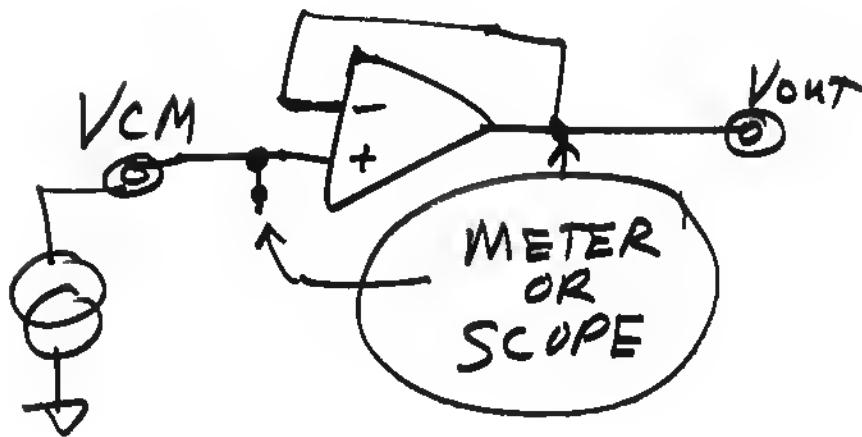
OK - NOW WE HAVE GOOD
OP-AMPS - HOW TO MEASURE?



$$V_{OUT} = A_V \times V_{CM} / CMRR$$

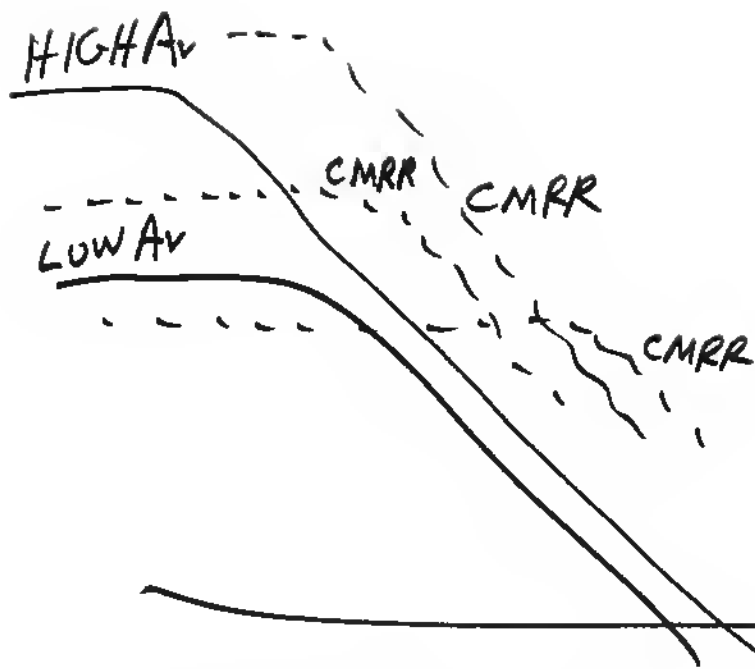
BUT THIS ONLY WORKS FOR
LOW GAIN - NOT FOR
OPAMPS...

IS THIS A GOOD WAY TO
MEASURE CMRR?



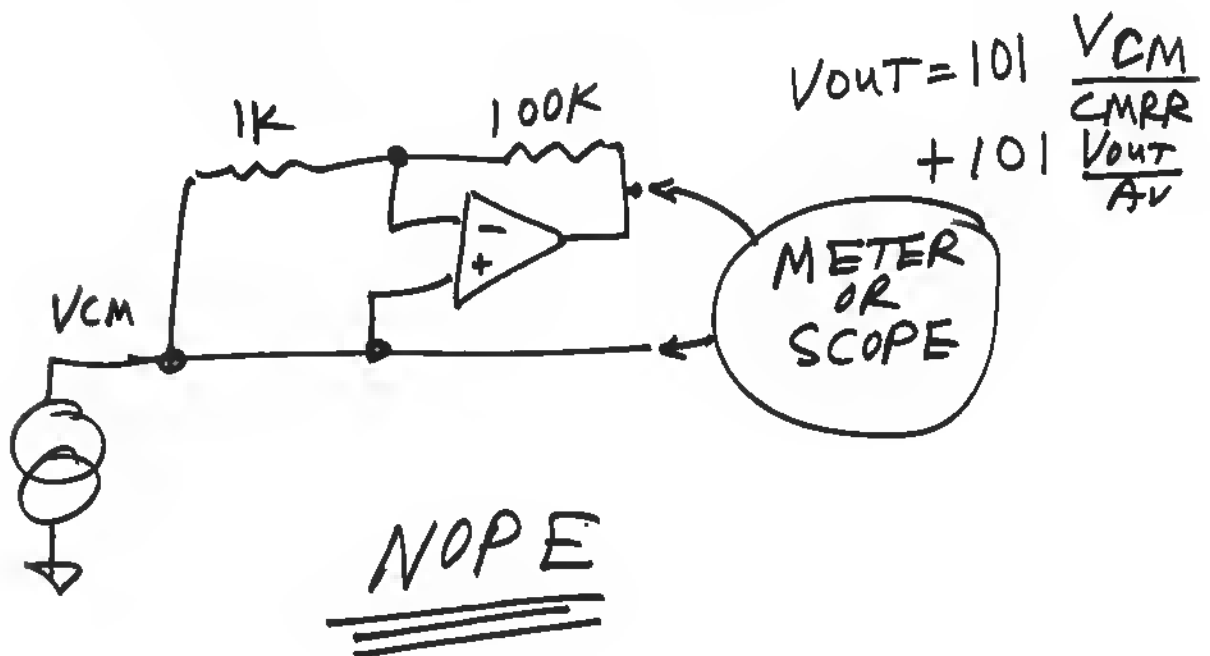
— NO —

RAP

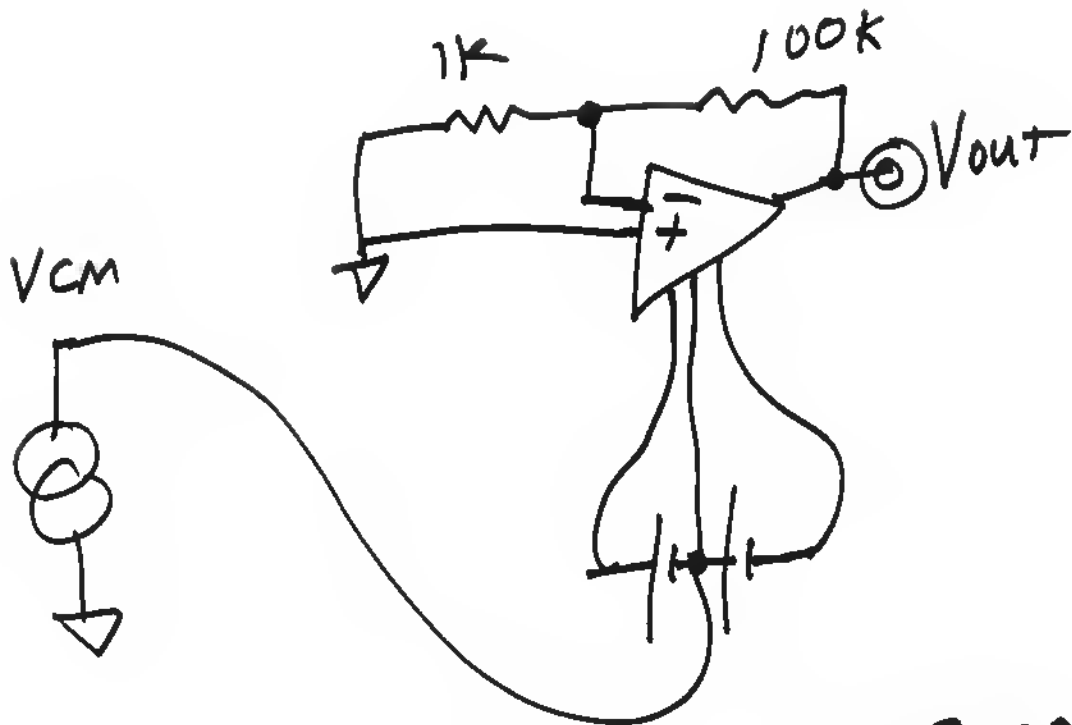


IN GENERAL - YOU CAN'T PREDICT
 HIGH OR LOW DC GAIN OR CMRR,
 HIGH OR LOW AC GAIN OR CMRR.

AH - THIS MUST BE A
GOOD WAY TO MEASURE CMRR



THIS HAS TO BE GOOD

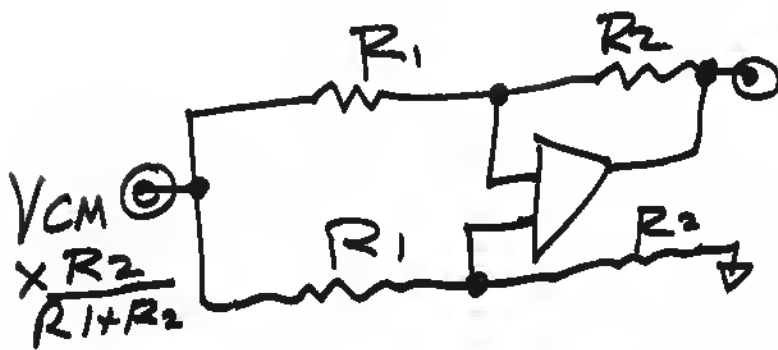


U/I - U/I. NOT GOOD

$$V_{out} = 101 [V_{cm} / CMRR + V_{out} / A_v]$$

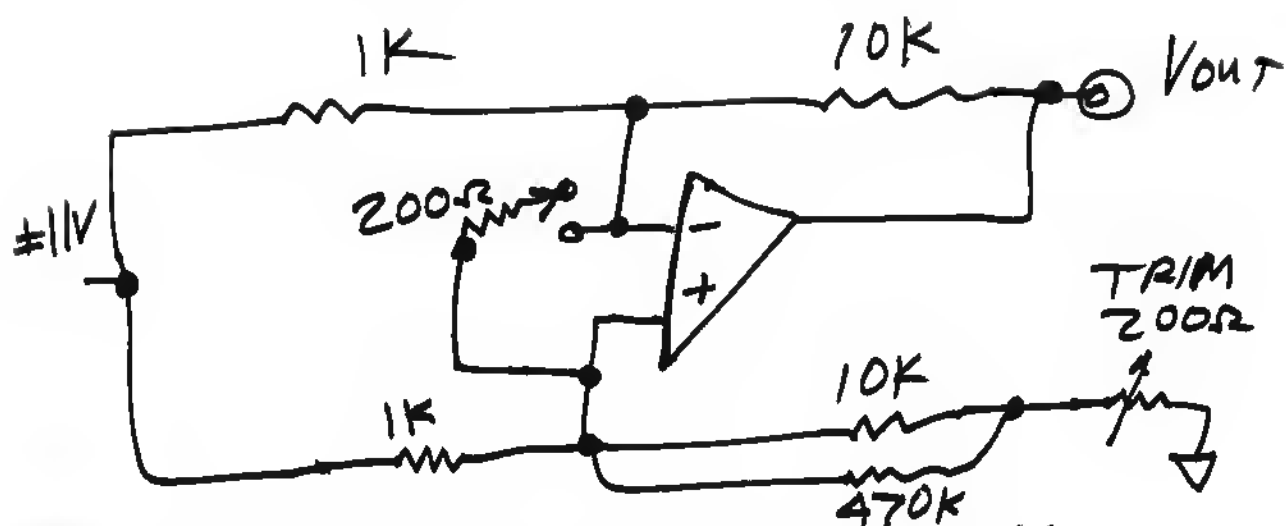
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OK, HOW ABOUT THIS ?
- ASSUME PERFECT RESISTORS



- THIS IS GOOD - NOW -
WHERE DO WE GET THE
"PERFECT R's" ??

AHA - WE'VE GOT IT!!



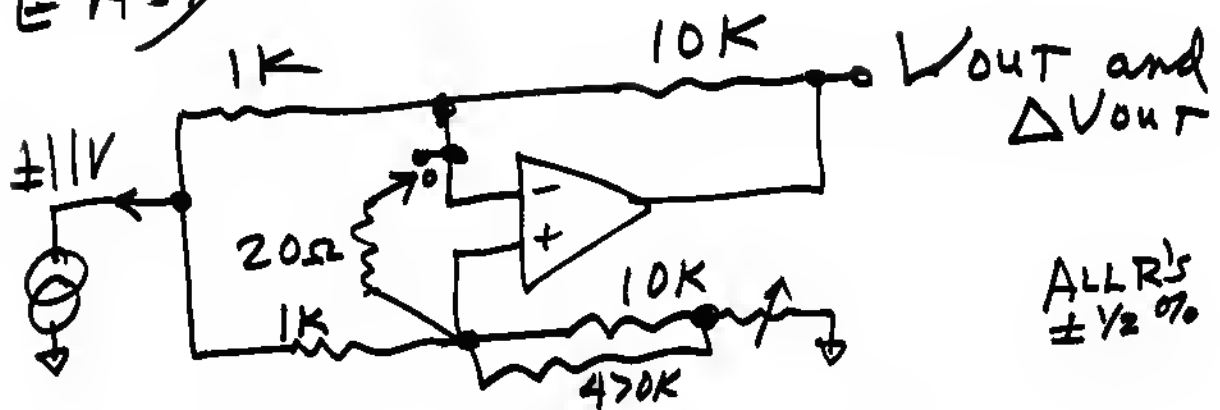
$$\text{NOISE GAIN} = 11 - \text{OR} - 111$$

$$\text{SO } V_{\text{out}} (\text{p-p}) = (V_{\text{CM}} / \text{CMRR}) \times 11 \text{ OR } 111$$

$$\text{THUS } -V_{\text{CM}} / \text{CMRR} \times 100 = \Delta V_{\text{out}}$$

WHAT IF YOU NEED TO
MEASURE CMRR > 110dB?

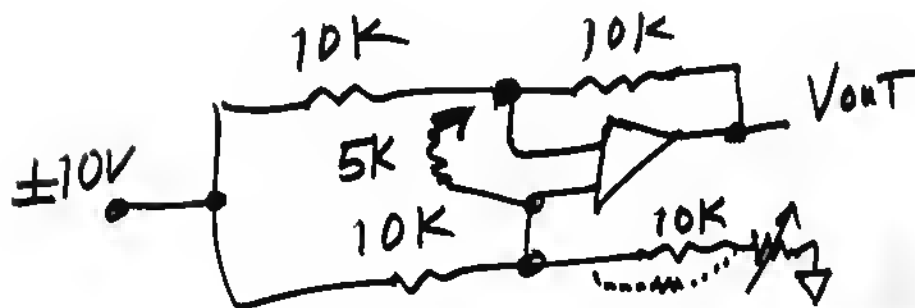
EASY!



NOISE GAIN = 11 or 1011

SO $\Delta V_{out} = [V_{CM} / CMRR] \times 1000$

WHAT IF YOU NEED
TO MEASURE CMRR
FOR 50KHz?



$$NG = 2 \text{ or } 6$$

$$A \times V_{CM}/CMRR = \Delta V_{out}$$

$$BW \cong GBW/10$$

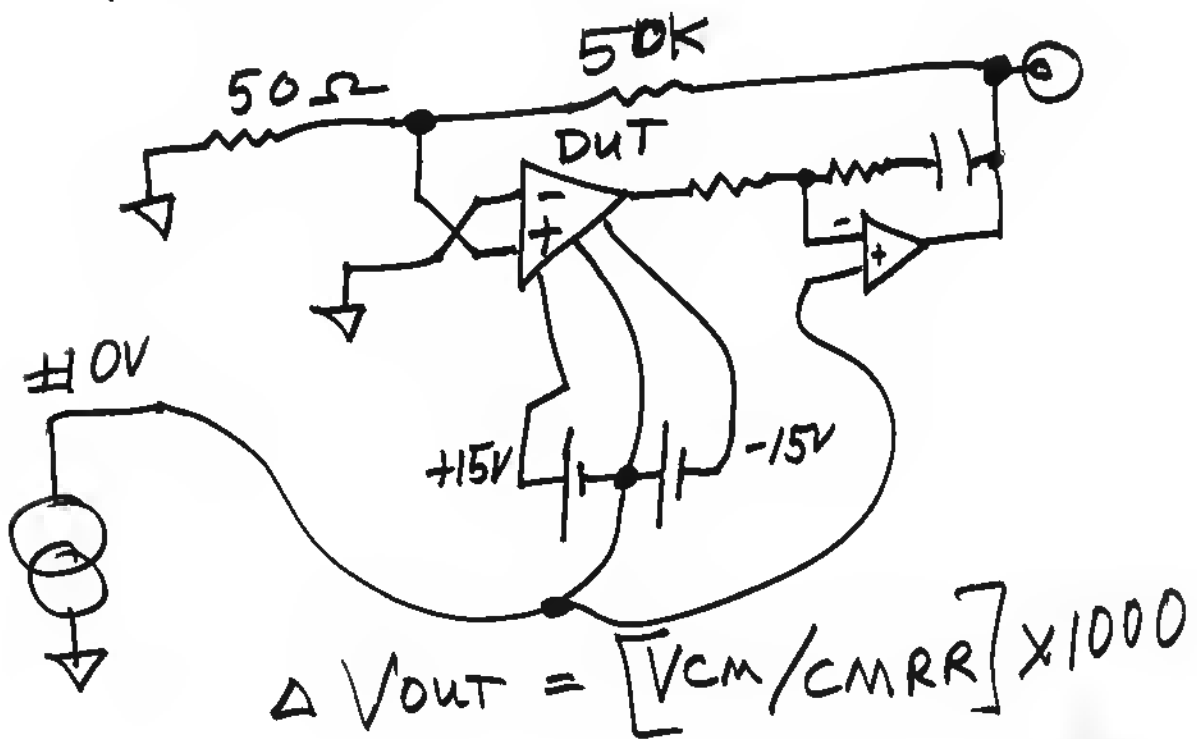
CAUTION!
DC CMRR

AC CMRR

NONLINEAR
ERROR
DUE TO
CM
SLEW
LIMIT



ANOTHER VALID WAY
TO MEASURE CMRR:



BUT,
BEWARE, THIS WORKS
ONLY AT DC & VERY
LOW FREQUENCIES.

- AC ERRORS ARE -
- UNSPECIFIED.

/RAP

What's All This

COMMON
MODE
REJECTION
STUFF?

(Anyhow.....)

Part III -
Rail-to-Rail
CM Range

RAP

LIST OF TYPICAL OP-AMPS WITHOUT $+V_s$ OR $-V_s$ Rail CM Range

- LM741
- LM725
- LM108
- LM709 — and —
- MANY MANY MORE....

LIST OF OPAMPS WITH
CM RANGE TO $-V_S$
[GROUND]

- LM 358 - LM 324
- LMV324 - LMV322 - LMV321
- LMC 660 -(QUAD) LMC 662 (DUAL)
- MANY MORE -
- PLUS - ALL RAIL-TO-RAIL -
INPUT CIRCUITS

LIST OF OP AMPS
WITH CM RANGE TO $\pm V_S$ -

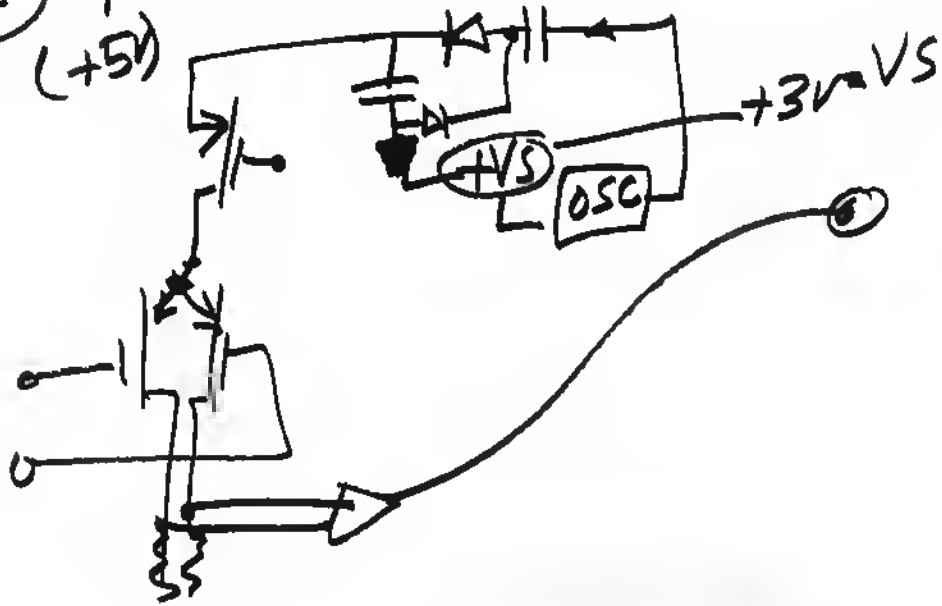
- LM101A - LM301A
- LF156 - 356
- LF411 - LF412 (DUAL)
- LF347, LF ~~4~~44
- LF351, LF 353

— AND- OF COURSE -

ALL RAIL-TO-RAIL INPUT
AMPLIFIERS

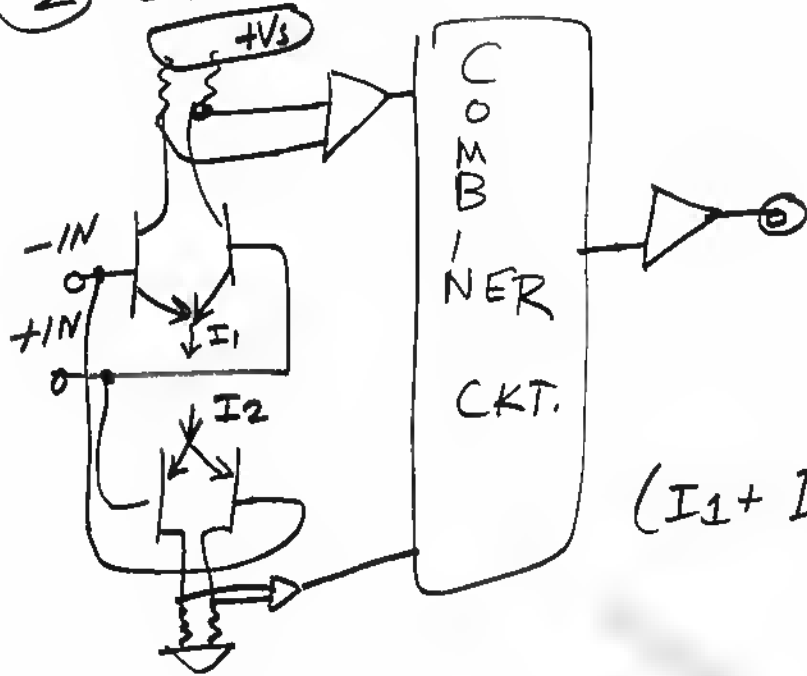
HOW TO MAKE - A - RAIL-TO-RAIL INPUT AMPL

① Pump IT UP -
(+5V)



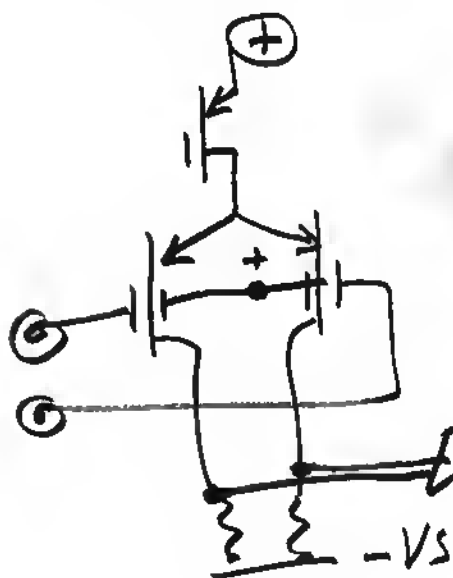
MAKE A R-R INPUT USING

② 2 INPUTS



$$(I_1 + I_2 \approx \text{CONSTANT})$$

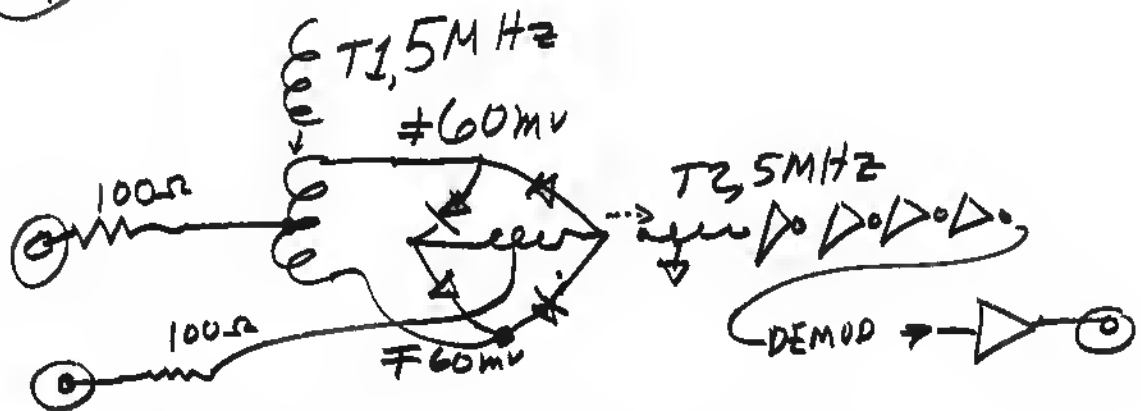
HOW TO MAKE R-R V_{cm} AMPLIFIERS USING SWOOPING MOS-FETS (U.S. PAT. ...)



ADVANTAGES -
- VERY LINEAR
- LOW NOISE
- HIGH Z_{in}

HOW TO MAKE HIGH CM Range...

④ USE TRANSFORMERS...



ADVANTAGES - $V_{CM} > 100\text{V}$
 - $Z_{IN} > 100\text{M}\Omega$
 - $L_{\text{NOISE}} - 1\mu\text{V for } 100\text{Hz}$

LATER WE'LL
EXPLAIN WHY
YOU MAY (OR MAY NOT)
NEED RAIL-TO-RAIL
C.M. RANGE

RAP

/more later. RAP

WHAT'S ALL THIS

CMRR
STUFF, ?

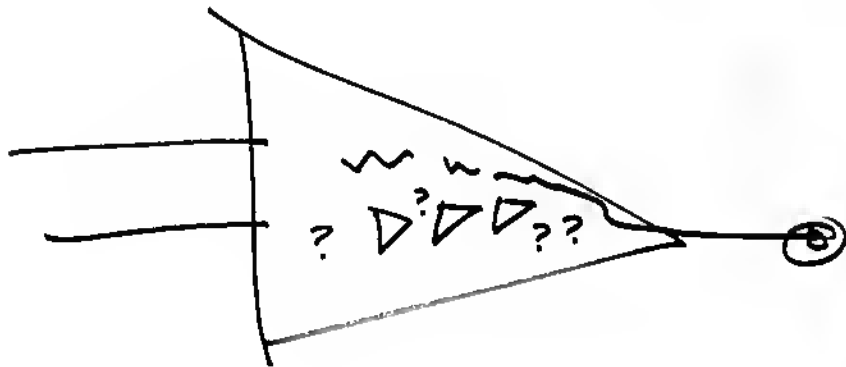
(Anyhow?)

(PART III)

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Differential Amplifiers

OR Instrumentation Amplifiers.



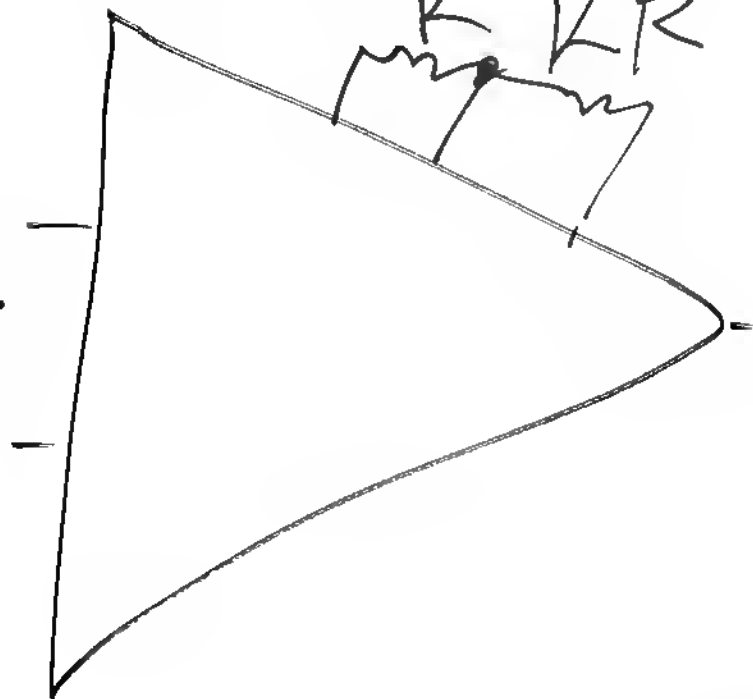
OK - WHAT IS
AN "INSTRUMENTATION
Amplifier"?

RAP

$$\text{GAIN} = K$$



$$Z_{IN} = \text{HIGH}$$

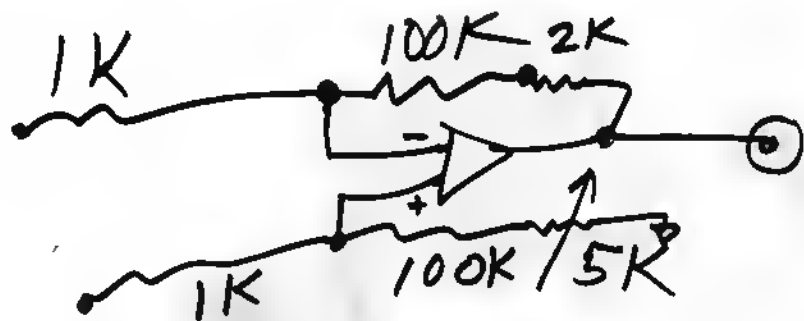


NOTE, THE OLD
MA725 data-sheet
SAID IT WAS "AN
INSTRUMENTATION
AMPLIFIER"

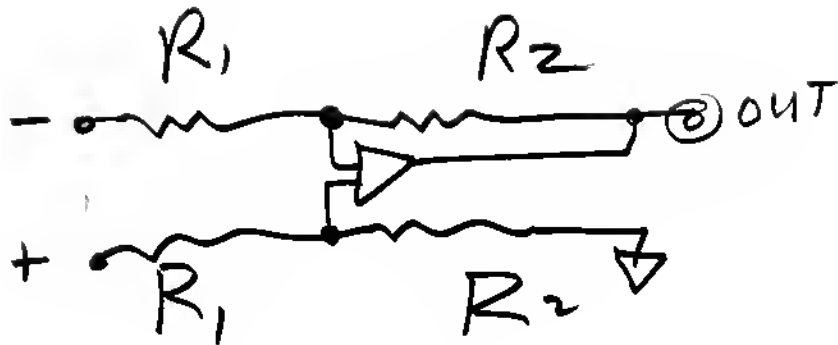
It wasn't....

It isn't....

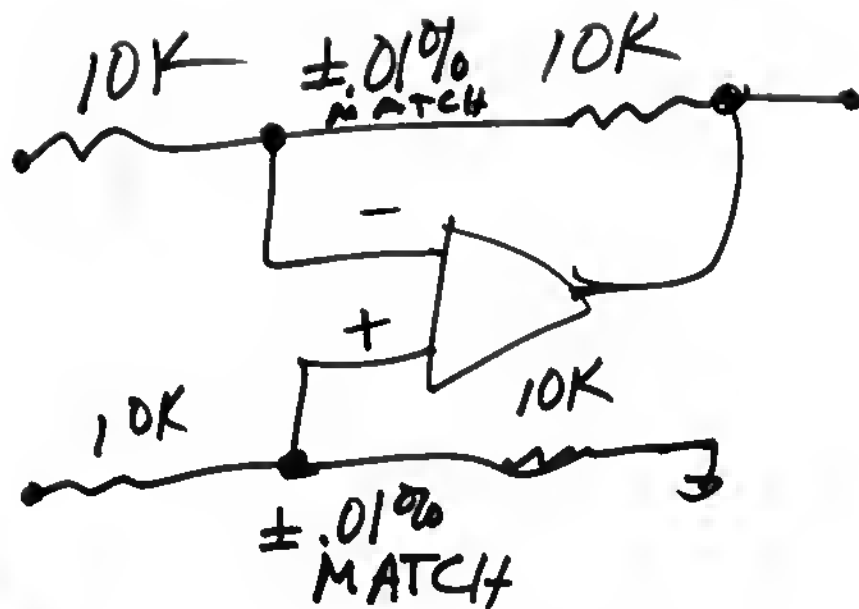
NOTE -
(almost) ALL
Instrumentation Amplifiers
need R TRIMS....



you'll need a TRIM POT.
for CMRR



- GOOD Differential Amplifier
- Needs TRIMS
- BUT - Z_{IN} ISN'T HIGH.....



YOU WANT
THIN-FILM
NETWORKS WITH
0.01% MATCHING....

NOT JUST FOR
CORRECTING
(CANCELLING OUT)
the OP-amp's CMRR

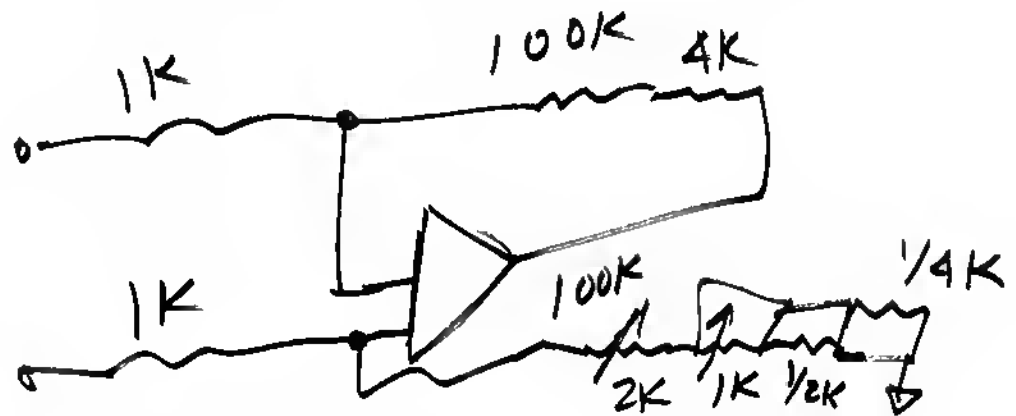
BUT R-RATIO

1% Resistors? Ha!

0.1% Resistors? (A BIT
BETTER.)

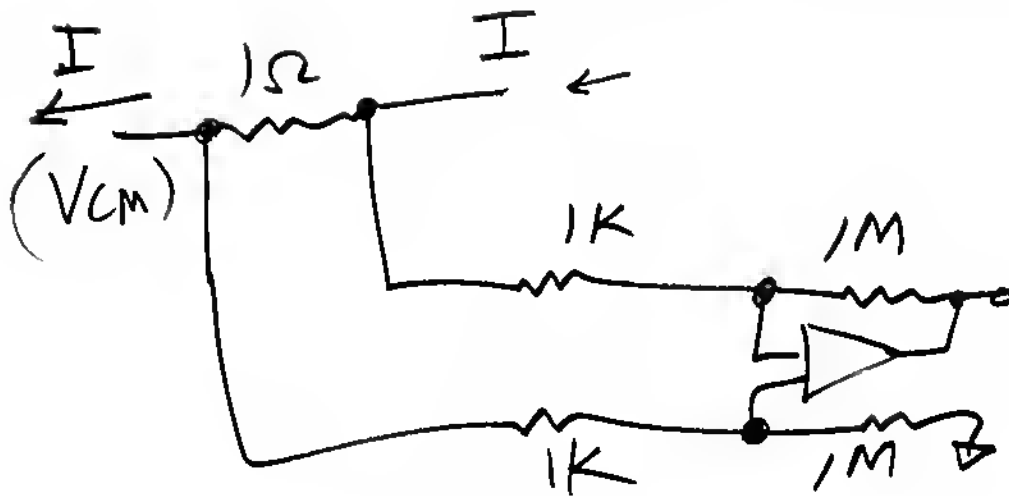
0.01% MATCH?

DO YOU WANT TO TRIM
YOUR CMRR
WITHOUT A POT?

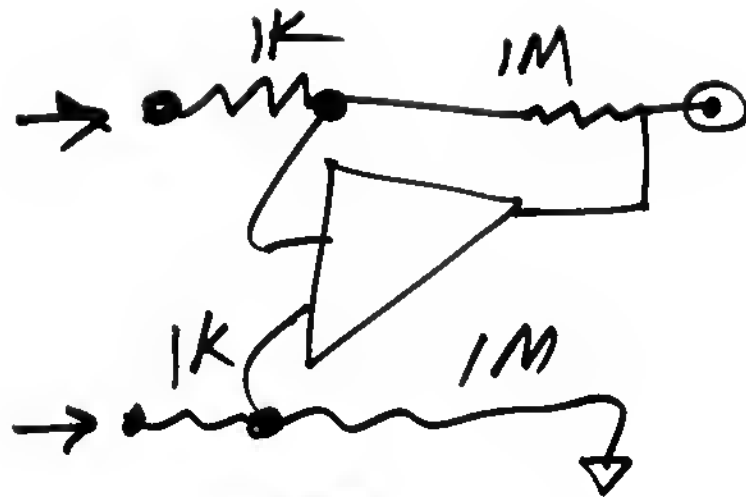


Refer to LB-46...

EXAMPLE ..

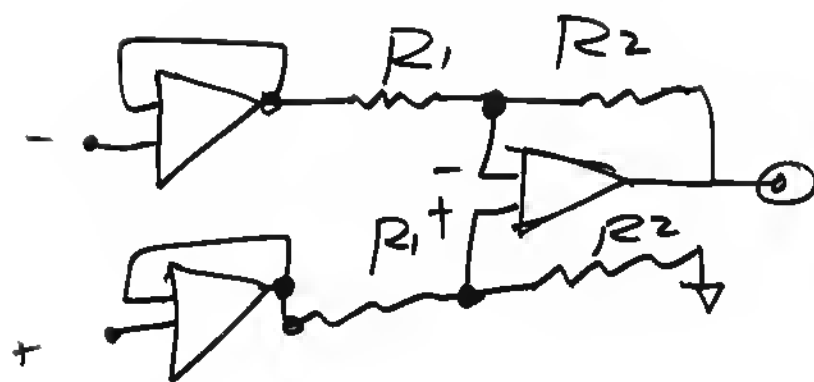


Beware of -
- V_{OS} -
- CMRR



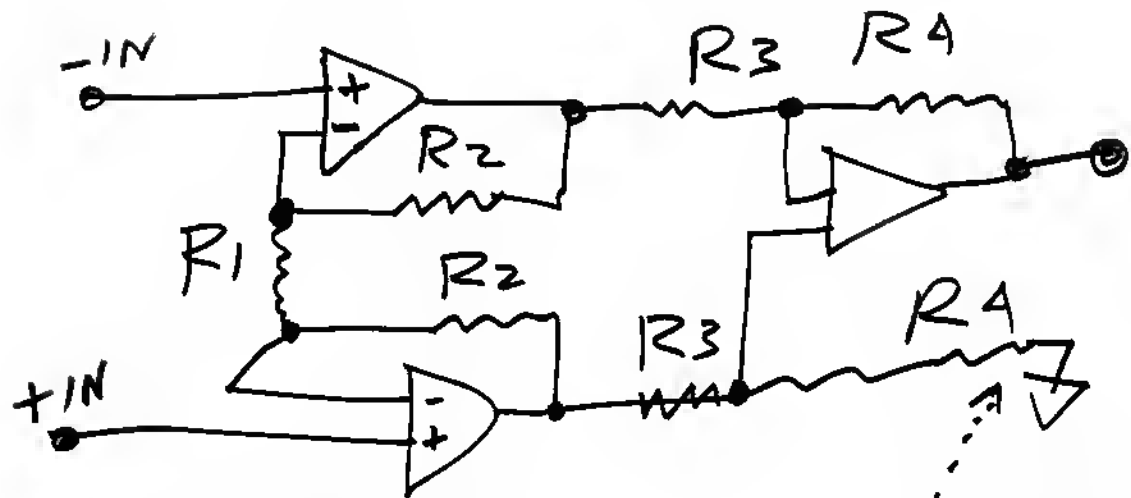
OK —
 what is the Z_{IN} ?
 $1k$?
 $1M$?

IMPROVED!!



PER THE LM102 Data Sheet....

REALLY GOOD
CIRCUIT !!!



- BETTER GAIN
- BETTER BW.
- BETTER CMRR.....

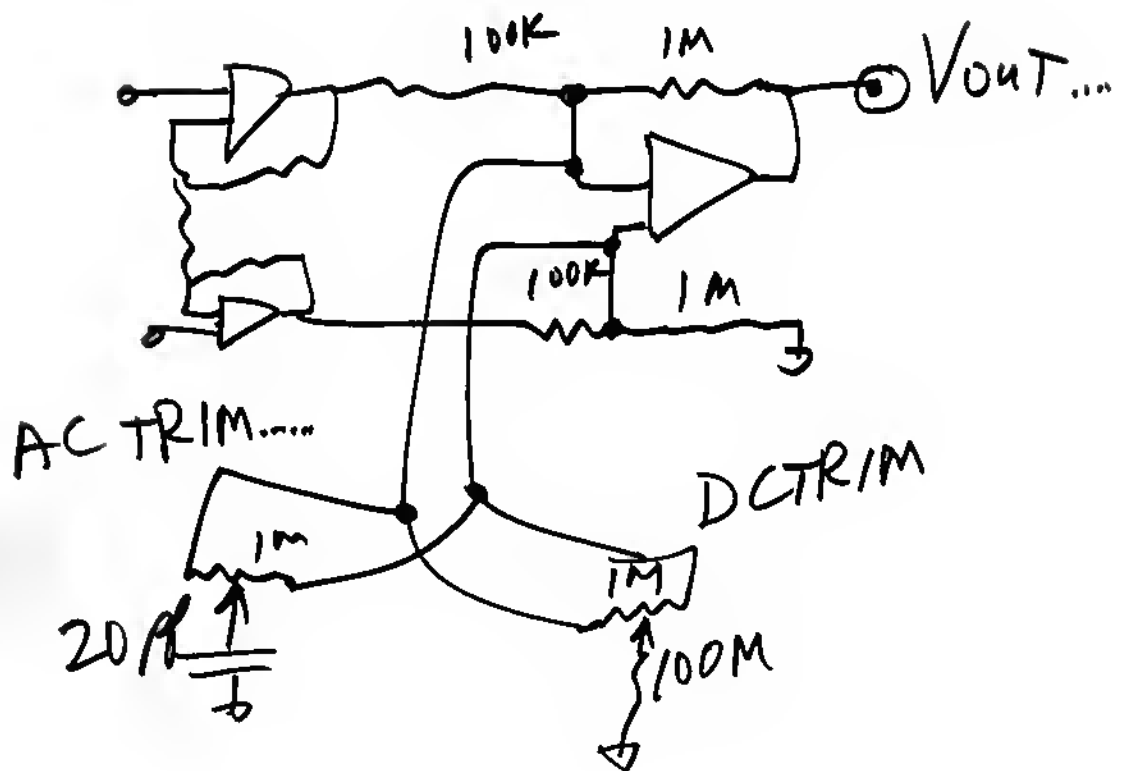
$$- G = (R_2 + R_2/R_1) + 1 \times (R_1/R_3)$$

- CMRR is improved

$$W \propto R_1/R_3$$

- BW is improved

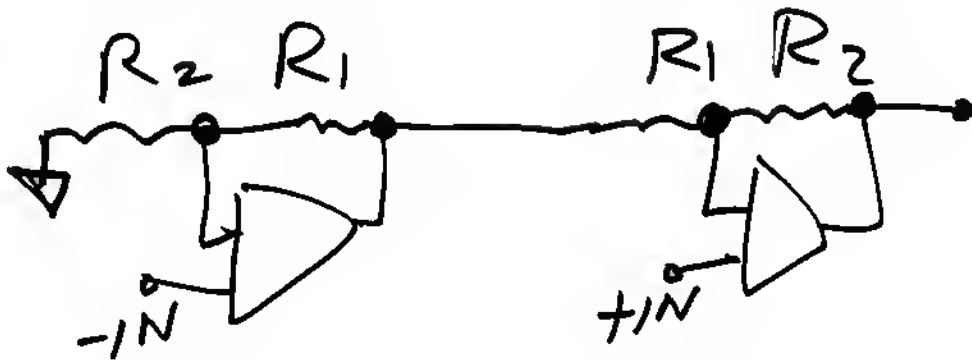
OTHER TRIM GAMES...



CAUTION ABOUT

C.M. SLEW
RATE

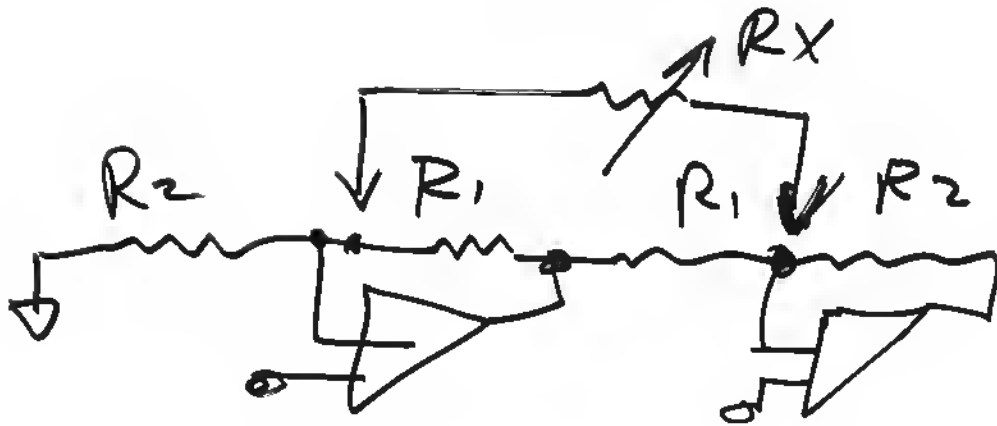
SIMPLER IS BETTER



$$G = \frac{R_2}{R_1} + 1 !$$

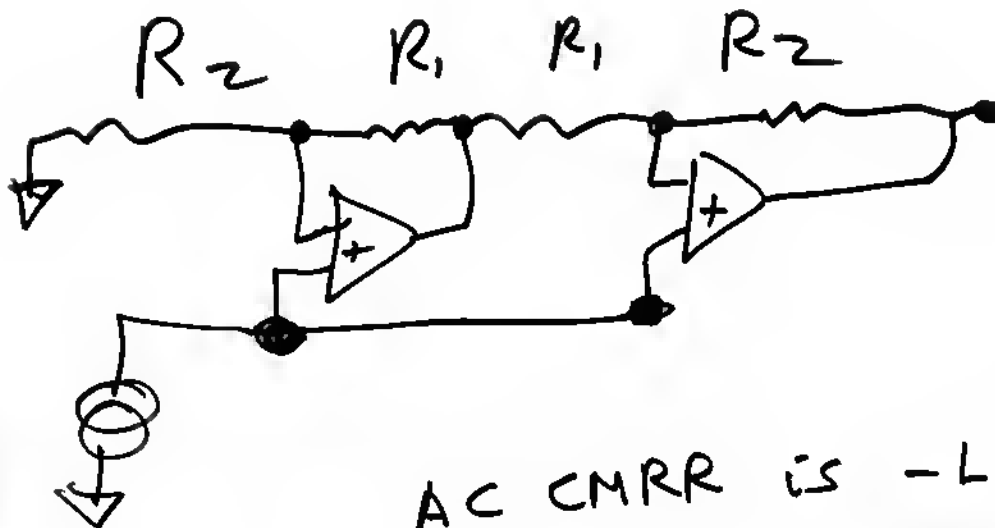
(Well, Maybe NOT....)

GOOD NEWS!

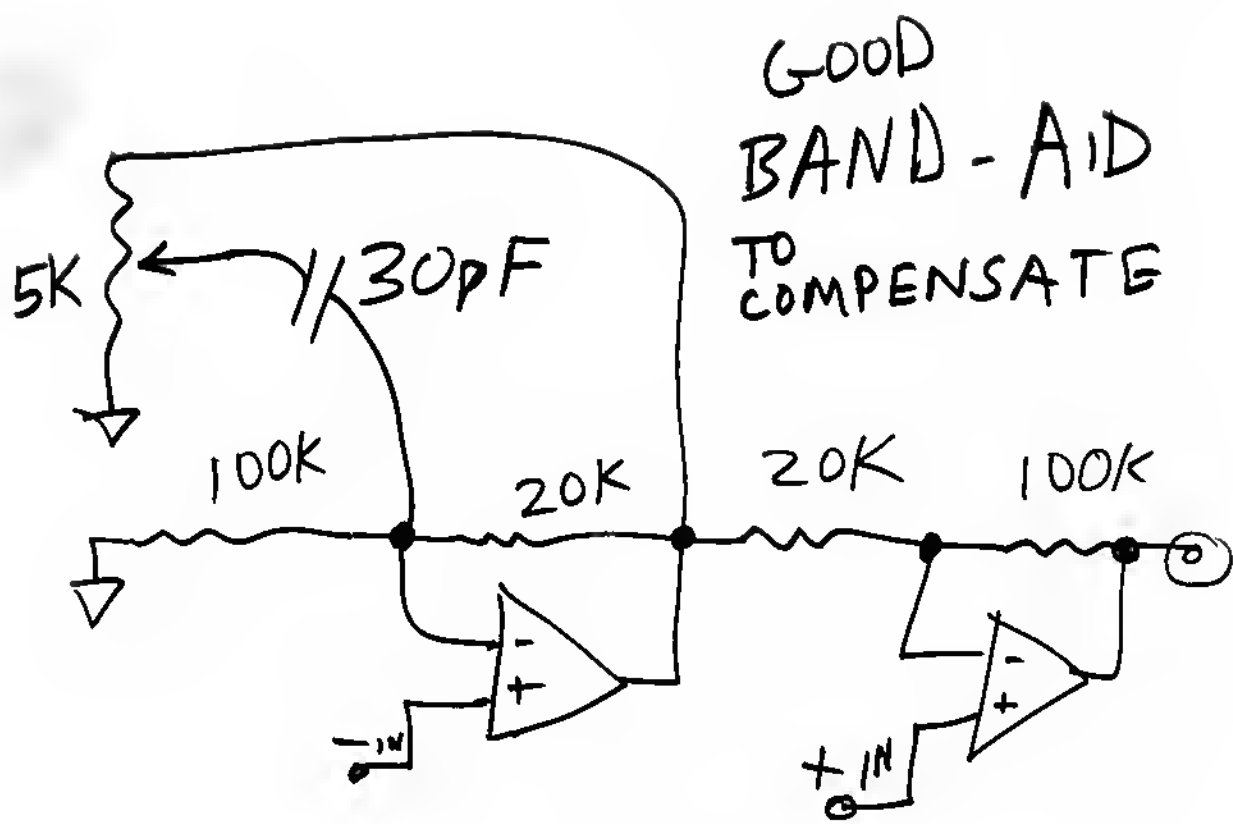


$$G = \left(\frac{R_2}{R_1} + 1 \right) + \left[\frac{2 R_2}{R_X} \right]$$

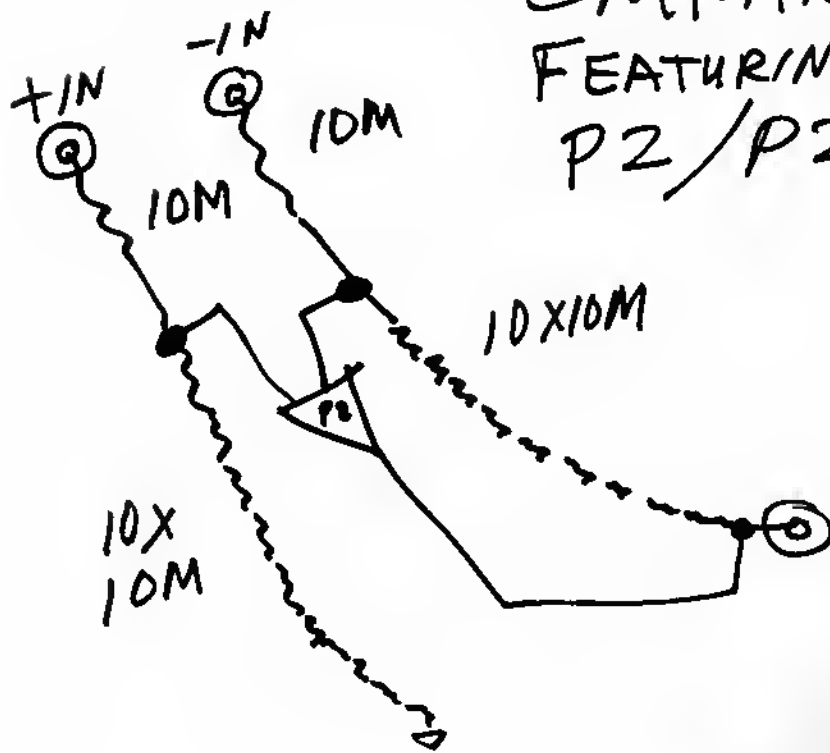
NOT SO GOOD NEWS..



AC CMRR is -LOUSY....



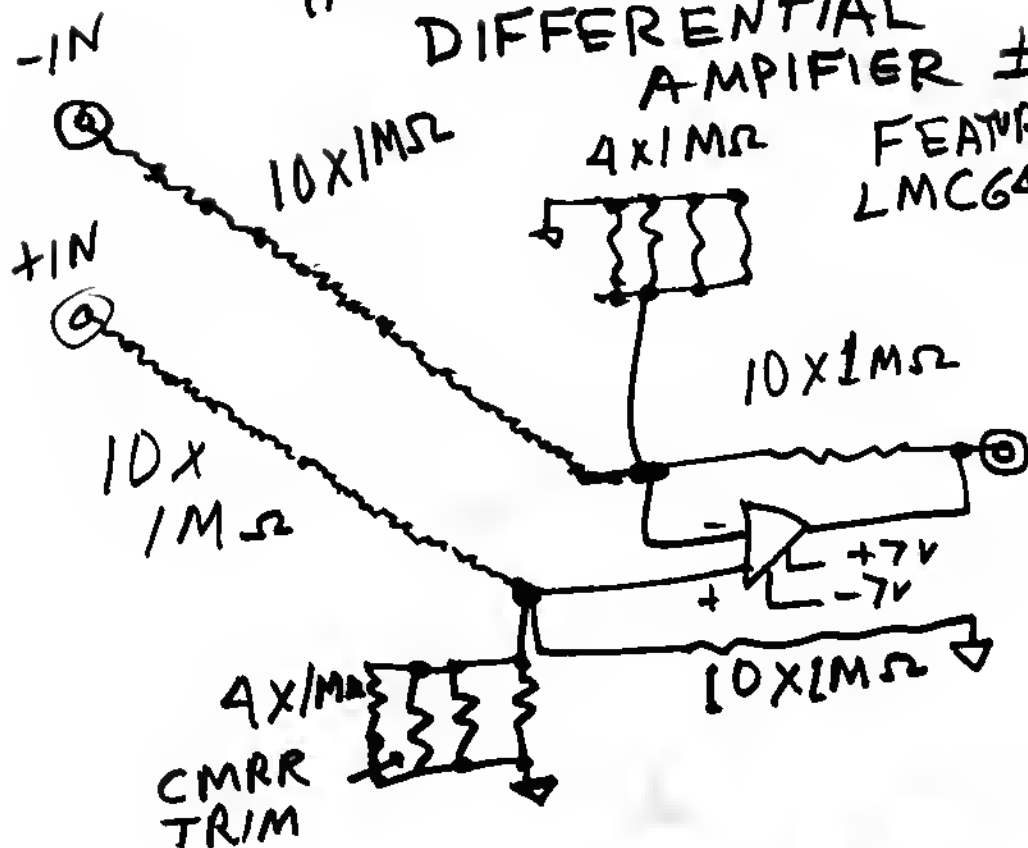
± 200 VOLTS of
CMRANGE
FEATURING
P2/P2A



HIGH CM-RANGE DIFFERENTIAL AMPLIFIER

$\pm 200V$

FEATURING
LMC6484



DOUBLE INPUTS

LMH 6645, -46 -47 -(55MHz)
LM 6152, 6154 (75MHz)
LM 7301 (TINY)
LM 6134, LM 6132 (LOW Power)
LM 6142, 44 " "
LM 8261, -62 -(∞ Cap Load)
LM V931, -32, -34 (1.8V Supply)

SMOOTH & SWOOPING

LMC 6482, -84

DUAL/QUAD

LMV 710, -711, -712

LOW PWR.

LMC 6462, -64

POWER

LMC 8101

SINGLE

QUAD

LMC 6494

WHAT'S ALL THIS STUFF, ?

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National Semiconductor provides a comprehensive set of support services. Product information, including sales literature and technical assistance is available through National's Customer Support Centers.

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The Bob Pease Show

All-analog talk show hosted by Bob Pease and streamed 24/7 from the National website.

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